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THE TRANSMISSION UNIT

BY

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A DESCRIPTION OF THE UNIT OF TELEPHONE TRANSMISSION
RECENTLY ADOPTED BY THE BELL SYSTEM AND
A DISCUSSION OF THE REASONS FOR ITS SELECTION

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The Transmission Unit

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IN what units telephone engineers express the grade of transmission of a telephone connection is a question of both technical and commercial importance. The advances that have been made in long distance telephony, both by wire and by radio, are emphasizing the need of cooperation in Europe in the engineering and operation of interconnecting systems. The simplifications in engineering specifications that would result if the present diversity of units in Europe could be replaced by a single one are obvious. At the same time the interchange of information through the technical press would be greatly facilitated.

The experience of the engineers of the Bell System led them, a short time ago, to the conclusion that the type of unit discussed in this paper is the most suitable for present conditions in the telephone art. This unit is called, for the present at least, the "transmission unit" and abbreviated *T.U.*[1] This unit was submitted for consideration to many of the leading telephone establishments of the world. The response to this proposal was favorable, in general, although there were several exceptions. The American Telephone and Telegraph Company are adopting this new unit as standard in the Bell System.[2]

The transmission unit is of the same general nature as the "Mile of Standard Cable at 800

[1] For convenience it is intended to dispense with periods and with *s* as indicating a number of *TU*.

[2] "The Transmission Unit and Telephone Transmission Reference System"; W. H. Martin; Journal of the A. I. E. E., June, 1924, p. 504.

Cycles" and the βl unit, both of which it is intended to replace. It is used to measure the same quantities as are now measured in those units. At the same time it is defined in such a way as to facilitate the extension of its application to meet the needs of the newer developments in the communication art. Its magnitude is very nearly the same as that of the 800 cycle mile. It is, however, so chosen as to make the use of common or Briggs' logarithms convenient in transmission computations. The number of 800 cycle miles corresponding to a condition wherein the currents under comparison are i_1 and i_2 is given by

$$N_M = 21.13 \log_{10} \frac{i_1}{i_2} = 9.175 \log_\epsilon \frac{i_1}{i_2}. \qquad (1)$$

If the comparison is between two powers P_1 and P_2,

$$N_M = 10.57 \log_{10} \frac{P_1}{P_2} = 4.587 \log_\epsilon \frac{P_1}{P_2}. \qquad (2)$$

The number of transmission units is given by

$$N_{TU} = 10 \log_{10} \frac{P_1}{P_2} = 4.343 \log_\epsilon \frac{P_1}{P_2}. \qquad (3)$$

This may also be written

$$N = \frac{\log \frac{P_1}{P_2}}{\log 10^{0.1}},$$

from which it follows that the TU is a logarithmic measure of power ratio and is numerically equal to $\log 10^{0.1}$.

The use of powers rather than currents is connected with the breadth of application already referred to, and will be discussed in more detail later. In case the currents associated with the powers under comparison are

proportional to the square roots of the powers, then

$$N_{TU}=20\ \log_{10}\frac{i_1}{i_2}=8.686\ \log_\epsilon\frac{i_1}{i_2}. \qquad (4)$$

Similarly the number of βl units is given by

$$N_{\beta l}=\log_\epsilon\frac{i_1}{i_2}=2.303\ \log_{10}\frac{i_1}{i_2} \qquad (5)$$

$$=0.5\ \log_\epsilon\frac{P_1}{P_2}=1.1513\ \log_{10}\frac{P_1}{P_2}. \qquad (6)$$

Choice of the Transmission Unit

Nature of the Unit

The reasons for selecting this particular unit rather than some other will probably not be obvious at first sight. They should, however, become apparent as we run over what the requirements for such a unit are, and in what respects the various possible units may differ from one another.

The "mile of standard cable" as originally used gave a means of comparing the loudness of the sound emitted by a receiver under any two conditions in terms of the number of miles of actual physical cable that had to be inserted under one of the conditions to make the two of equal loudness. In practice, of course, adjustable artificial cables were used. The definition of the unit then was in terms of the constants per mile of the cable chosen as standard. Unfortunately two slightly different cables have become standard. That used in America has a loop resistance of 88 ohms and a capacity of .054 microfarads per mile. Some of the other countries use a cable of the same resistance and capacity which has in addition an inductance of 1 milhenry and a conductance of 1 micromho per mile.

The effect on the output of the receiver of inserting such a cable is much greater at high frequencies than at low; that is, it distorts the speech at the same time that it attenuates it. Moreover, the distortion increases with the length of the cable used. This distortion was rather a desirable property so long as the use of the unit was confined to talking comparisons of lines having roughly the same distortion as the standard cable. This condition no longer exists, however. Many of the circuits now in use have much less distortion than has a length of standard cable having the same attenuation. Also the unit is used to express the effect of inserting pieces of apparatus whose frequency characteristic bears no resemblance to that of the cable. In America at least the use of voice testing in the plant has been practically replaced by methods employing sine wave currents and electric measuring instruments. As these tests may be made with currents of various frequencies, it is important that the results be expressed in units which are independent of the frequency.

As this need arose it was natural to adapt the existing unit to meet it. Thus the effect of the circuit under test for a current of any particular frequency came to be compared with that of the standard cable for a current of one standard frequency; namely, 796 cycles per second, for which $2\pi f = 5000$. In this way a new unit was introduced which came to be called the "800 Cycle Mile." It has, of course, two slightly different values corresponding to the two specifications for the standard cable. So far as our further discussion goes we may eliminate the original mile of standard cable as a possible unit on the ground that it fails to meet the fundamental requirement of being independent of frequency.

Before proceeding, however, let us look more carefully at what was involved in the transition

to the 800 cycle mile. The artificial cable box has been replaced in substitution measurements by an artificial line calibrated in 800 cycle miles, which is made up of resistances only and so has the same effect on all frequencies. This fact tends to suggest that the 800 cycle mile, like the mile of standard cable, has, or may have, an actual physical existence. This, however, is not the case. The 800 cycle mile is a purely theoretical unit based on certain mathematical relationships. This is evident from the fact that the specifications to be met in designing a "resistance line" are that the overall effect shall vary with the length in the prescribed fashion, whereas the magnitude of the resistances used and their particular arrangement in the circuit is immaterial. The theoretical nature of the unit is still more evident when it is used for expressing the transmission of a system as determined by the ratio of two electric quantities such as currents, which may have been either measured or computed without making use of any artificial line.

The relation which defines the unit is that which connects the number of miles of standard cable with the effect which it produces at 800 cycles. The particular effect which came to be most commonly taken as a criterion was the ratio of the received current before and after the insertion of a length of standard cable. To avoid ambiguity due to terminal conditions, the line was assumed long enough so that the effect of the inserted cable is independent of the impedances at the ends of the cable in which it is inserted. The ratio of the currents under these conditions is identical with that of the currents at two points in an infinite line separated by a length equal to the number of miles inserted. This ratio $\frac{i_1}{i_2}$ is an exponential function of the distance x, which, because of the

occurrence of the naperian base ϵ in line theory, is ordinarily expressed in the form

$$\frac{i_1}{i_2} = \epsilon^{ax}, \tag{7}$$

where a is a constant depending on the cable and the frequency. It should be noted, however, that the use of ϵ is purely arbitrary, as the relation can be completely expressed with a single constant as,

$$\frac{i_1}{i_2} = b^x, \tag{8}$$

where

$$b = \epsilon^a. \tag{9}$$

For the standard cable in use in America a is 0.109, from which

$$b = 1.115 \tag{10}$$

The arbitrary introduction of this unnecessary constant ϵ is only justifiable if it simplifies the treatment of the whole problem. Since, as will be brought out more fully later, it is uniquely related to only a small part of transmission engineering, its inclusion at this point tends rather to confuse than clarify the situation.

Expressing the number of units x as an explicit function of the current ratio gives

$$x = \frac{\log \frac{i_1}{i_2}}{\log b}. \tag{11}$$

From this expression we may deduce the nature and magnitude of the 800 cycle mile as a unit. If we wish to find the number of seconds in any interval of time we divide the length of the interval by the length of the second. If we want the number of hours we divide by the length of the hour. Here the quantity which the

unit expresses is the logarithm of a current ratio. The number of units x is the logarithm of the ratio being measured divided by the unit, which is log b. Thus the nature of the unit is the logarithm of a current ratio. Its magnitude is the logarithm of that particular current ratio b which is chosen for defining it; in this case 1.115. It should be noted that (11) is true regardless of the base of the system of logarithms used. *The numerical value of the unit will, of course, vary with the base chosen, but the number of units corresponding to the particular current ratio will not.*

The βl unit is of the same nature as the 800 cycle mile, and differs from it only in its magnitude, which has been selected to facilitate the computation of the transmission of a long line from its primary constants. Its theoretical basis is more obvious than in the case of the mile, although its evolution from the theory of line transmission has tended to associate it more closely with long lines than is perhaps justified in view of the other uses to which it is now put. Thus while the idea of its being the product of a length by an attenuation per unit length is retained in the symbol βl, for practical purposes a single letter would be equally useful.

The βl unit, like the 800 cycle mile, is the logarithm of a current ratio. The number of units is given directly by the natural logarithm of the current ratio in question. Thus in (7) a is unity. This means that in (11) b is equal to ϵ, and so the unit itself is log ϵ. When expressed in natural logarithms the absolute value of the unit is therefore unity, as would be expected.

The *TU* is like the other two units in that it is defined theoretically and measures the logarithm of a ratio. The fact that the ratio measured is that of powers rather than currents is a separate question from that of its meeting the fundamental requirement of being the logarithm

of a ratio.[3] The magnitude of the transmission unit is readily deducible from the relation given in (3). Dropping subscripts, this may be written

$$\frac{P_1}{P_2} = 10^{0.1N} = b^N, \tag{12}$$

where

$$b = 10^{0.1} \tag{13}$$

Corresponding to (11) then,

$$N = \frac{\log \frac{P_1}{P_2}}{\log 10^{0.1}}. \tag{14}$$

Following the same reasoning as was applied to (11) with reference to the 800 cycle mile, we see that the *TU* is a unit for expressing the logarithm of the ratio of two amounts of power, and that it is numerically equal to the logarithm of a power ratio of $10^{0.1}$. When common logarithms are used its value is 0.1 and the number of units corresponding to any power ratio is ten times the common logarithm of the ratio.

Reasons for Using Power Ratio

Before discussing the reasons for proposing a unit based on power rather than current ratio some misunderstanding may be prevented by pointing out that the power ratio as here used is not to be confused with the ratio commonly used for expressing the efficiency of electrical or other machinery. It is not necessarily the ratio of the power delivered by a device to that entering it, but may be the ratio of any two amounts of power whatsoever. Just what powers are to be taken in any case will be de-

[3] Units of this general type are not confined to transmission, but have come into use for expressing various ratios. Thus the octave and the musical tone are units of different magnitudes for expressing the logarithm of a frequency ratio. The stellar magnitude is one for expressing the logarithm of the ratios of the light received from the stars. They all are aimed at substituting addition for multiplication in combining ratios.

termined by what quantity is being measured in transmission units and how that quantity is defined. It may, for example, be the efficiency of a system as compared with some reference system, the crosstalk between two lines, or the relative power at two points in a system.

No attempt will be made here to define these quantities beyond pointing out that it can be done more generally in terms of powers than currents. As the general includes the special, such a definition need not interfere with the practical use of currents under those conditions where this gives satisfactory results. That there are, however, conditions under which this is not the case is evidenced by the fact that in certain branches of transmission engineering the "800 cycle mile" has already come to be used as a unit defined on a power basis. In laying out a circuit containing a number of repeaters it is customary to construct what is called a transmission level chart.[4] Corresponding to each point along the circuit is plotted the "level" at that point relative to some point, usually the entrance to the long distance line, which is taken as a reference level. The level at any point is determined by the ratio of the power passing that point to that passing the point of reference. The purpose of such a chart is to indicate on the one hand what power the various repeater tubes will be called upon to handle, since they are limited in this respect, and, on the other hand, what is the ratio of the power of the voice currents to that of the interfering currents. This ratio is important because it determines the detrimental effect of the interference when it reaches the listener. These relative levels are most conveniently plotted in logarithmic units, so it was natural to use 800 cycle miles. Since, however, the impedances

[4] Telephone Transmission over Long Cable Circuits: A. B. Clark; Trans. A. I. E. E. Vol. XXXVIII, Part 2, p. 1287, *Electrical Communication*, Vol. I, No. 3. Feb., 1923.

of the various line sections and of the apparatus including vacuum tubes vary over a wide range, a very misleading picture would be obtained if the ratios of the currents at the various points to that at the reference point were used directly in calculating the levels. To avoid this difficulty and still permit the use of formulæ based on the mile as defined in terms of current ratio, the square root of the power at the various points has come to be used as a sort of fictitious equivalent current. Had the impedance been the same at all points, the use of the currents directly would have given a correct picture.

This example serves to illustrate the arguments in favor of the power ratio unit. It brings out the fact that the really important quantity in transmission is the power. So long as the powers under comparison are associated with equal impedances, the corresponding currents give a correct measure of relative powers. In the earlier stages of the art very few of the comparisons were between powers in unequal impedances, and so a current unit was satisfactory. The more recent developments, particularly those associated with the use of vacuum tubes, have introduced an increasing proportion of cases in which the impedances are unequal, and hence an increasing demand for a unit which expresses power ratio regardless of the associated impedances. Such an extension of the unit in no way interferes with the use of current ratios in cases involving equal impedances, such as the computation of specific equivalents of lines, or the determination of transmission loss by observing the change in current in a fixed receiving instrument. All that is necessary here is to use twice as large a constant in the formula when computing units from the current ratio as is used for power ratios. Thus the number of *TU* is twenty times the common logarithm of the current ratio.

Some other illustrations of cases where a current ratio unit is inadequate may be mentioned.

Receivers are often compared by determining the ratio of the currents which must be passed through them to secure the same loudness of sound from both. Such a comparison means very little unless the impedances of the two happen to be the same. A high impedance receiver appears at a distinct advantage in such a test, owing to the fact that it receives more power for the same current flowing through it. For such a test to give a true picture, correction must be made for the difference in impedance in a manner which is equivalent to reducing the comparison to a power basis.

In computing the transmission efficiency of a line involving inserted apparatus a type of quantity which has been found quite useful is the so-called loss at a junction. This includes reflexion, transition and other similar losses. These can be expressed independently of the rest of the circuit in the form of the ratio of the power actually transferred across the junction to what would be transferred if the circuit receiving the energy were replaced by one having an impedance, as measured from the junction, bearing some prescribed relation to that of the circuit supplying the energy. Such a loss is expressible directly in terms of the power ratio used, whereas the application of a current ratio unit to such a case is forced, to say the least.

Again, in the application of line transmission methods to radio telephony[5] level diagrams similar to those on long lines are useful. Here we may wish to compare power in the form of ether waves with that in the form of currents in wires. Just what currents would here be used is not obvious.

[5] Application to Radio of Wire Transmission Engineering: L. Espenschied; Inst. of Radio Eng., Oct., 1922, p. 344.

In the treatment of the mechanically vibrating parts of a telephone system, such as a receiver, there is a tendency in the direction of considering the electrical and mechanical parts as a continuous transmission system. In such an arrangement the comparison of electric and mechanical power at two points would be natural in terms of a power ratio unit, whereas the analog of a current ratio would be the ratio of current to mechanical velocity.

It might be argued that the use of a power ratio would be undesirable because there is no instrument available which measures power directly. This difficulty is, however, more apparent than real. Power is commonly measured in telephony by measuring a current (or voltage) in an impedance which is known either by measurement or by computation. The use of current ratios as a measure of transmission is all based on an implied knowledge of the impedances involved, or at least of their relative values. Where this knowledge is available no more measurements are required to give the necessary information about the powers than about the currents. Where it is not available the same steps as are involved in measuring powers must be taken before a knowledge of the currents can have any significance as a measure of transmission. The desire to measure power arises from its own importance in engineering, and not from any arbitrary selection of a unit. That it cannot be measured directly may perhaps be considered unfortunate, but it would be more unfortunate still if, having measured it by indirect methods, no units were available for expressing the result.

Nor does a definition in terms of power ratio do any violence to the concept of the unit as being derived from the standard cable or the so-called "unit line," which is sometimes associated with the βl unit. It will be remembered that in tracing the evolution of the 800 cycle

mile there was found a point at which it was necessary in fixing the unit to choose some criterion of the effect of the cable on the wave transmitted over it. While its effect on the current has been most commonly chosen, there can be no logical reason other than usefulness for choosing this rather than any one of the other quantities which are affected, such as voltage or power. Since, however, experience is showing power to be the most useful quantity it is obvious that if the 800 cycle mile continued in use its natural evolution would be to a power basis. The same is true of the βl unit. It would seem foolish, therefore, to set up a new unit on anything but a power basis.

The question of power ratio is really one of making the definition of any unit of the type under consideration broad enough to meet the needs of the art. All of the proposed units may be so defined without restricting their usefulness in other directions. Assuming that this is done, the choice between them is then to be based on other considerations.

Size of Unit

Units which are independent of frequency and measure the logarithm of a power ratio may differ only in the magnitude of the unit; that is, in the ratio corresponding to one unit. Here two factors are important: the order of magnitude of the unit and its relation to the systems of logarithms in common use. Obviously the simplest units from the latter standpoint would be the logarithms of power ratios of 10 and ϵ. Their values would then be unity in the common and natural systems, respectively. However, if some other order of magnitude is more desirable it may be approximated with either system by taking a multiple or sub-multiple, just as the kilometer and centimeter are derived from the meter. The TU is such a sub-multiple of the simplest unit employing the base 10.

Let us consider then the approximate size of the unit regardless of the logarithmic base. This question is complicated by the fact that two quite different sizes are already in use. Those familiar with each have acquired a sense of the practical significance of any particular number of the units to which they are accustomed. Also measuring apparatus and data adapted to each unit have been accumulated. The adoption of any universal unit must therefore involve a considerable readjustment of ideas, and some expense in conversion of equipment and data. The aim then should be to make this readjustment as small as is consistent with making the most of the rare opportunity of selecting the intrinsically best size of unit.

Other things being equal, there is some advantage in a unit which bears a unique relation to the physical quantity which it measures. The *TU*, like the "800 cycle mile," represents about the least difference in loudness which can be detected by the ear without special training. From this standpoint, therefore, it is preferable to the βl unit. From the standpoint of practical convenience the use of unnecessarily large or small numbers in expressing commonly occurring quantities is to be avoided. With a unit of the size of the *TU* it is seldom necessary to use more than two places on either side of the decimal point. Losses approaching 100 *TU* may be encountered in crosstalk considerations, for example, while the loss of an individual circuit element such as a transformer may be expressible in hundredths of a *TU*. Even such small losses may become important where the cumulative effect of a large number is involved.

The situation, then, is that the adoption of a unit of the size of the *TU* involves a considerable readjustment on the part of the users of the βl unit and a comparatively small readjustment by the much greater number of users of the 800 cycle mile. At the same time, it gives

some advantages which are inherent in a unit of that general size. The adoption of a unit of the size of the βl, on the other hand, would involve practically no readjustments by those now using βl, but extensive readjustments by those using the mile. It would seem then that the greatest advantage with the least sacrifice would be given by the smaller unit.

Logarithmic Base

Coming back to the choice between a unit adapted to the use of common vs. natural logarithms, we may be guided by the general principle that in the scientific and engineering world common logarithms have been shown by their extended use to be the more convenient except in cases where some special consideration makes natural logarithms preferable. Unless, therefore, it can be shown that such a special consideration holds in the case of transmission engineering, it would be going against well established experience to select anything but common logarithms.

The occurrence of the base ϵ in formulæ for line attenuation might be advanced as such a special consideration. While it is true that the computation of the attenuation of a uniform line from its primary constants is simplified by using natural logarithms, the cases where such an advantage exists form a small and progressively decreasing part of all the uses of such a unit.

The practice in certain countries of solving apparatus problems by reducing them to equivalent smooth lines tends to give the impression that the natural base is uniquely related to a larger field of computation than is actually the case. Most of these problems can be solved at least as easily by other methods which do not introduce the natural base. There are, in fact, two distinct methods of attacking

circuit problems in current use. The one which is used largely in those countries where the βl unit is employed reduces everything to its equivalent smooth line. The other, which is more generally used elsewhere, reduces the part of the circuit under consideration to a relatively simple network, which may then be solved by the application of Kirchhoff's Law. Natural logarithms are doubtless more convenient for the first method, and common logarithms for the second. So far as the theoretical man is concerned the choice of unit then would be based on which of these methods is preferable. A consideration of this question seems to indicate that of the problems encountered in practical work none are solved more easily by the first method than the second, whereas a considerable number are solved more easily by the second. If this is true, the second method should ultimately replace the first, and the demand for the base ϵ, except for long line computations would then largely disappear.

The increasing use of interconnected lines of different types and of terminal equipment, such as repeaters and carrier current apparatus, is reducing the relative importance of long line computations. Also as a reference to the illustrations cited under the discussion of power ratio will show, there is coming to be an increasing need for expressing power ratios which are measured or else calculated by formulæ which do not involve ϵ. Much of this work is done by men engaged in the more practical phases of engineering, to whom the convenience of common logarithms is very considerable. The fact that the ordinary slide rule gives the result directly in such cases is a point of considerable importance. On the other hand, the cases in which natural logarithms are of advantage are handled largely by men of considerable training, to whom the conversion to common logarithms

may offer a slight inconvenience in manipulation, but no theoretical difficulty.

In view of these considerations it does not appear that transmission engineering is so different from other branches as to justify a special type of logarithm.

Use of the Transmission Unit

Transmission Reference System

It was emphasized in the foregoing discussion that the *TU* is suitable for expressing a wide variety of different quantities. Space will not permit a discussion of all these, but there is one which deserves attention because of its own importance and because of the fact that its measurement involves the use of physical standards. This is the measurement of the overall reproduction efficiency of a system for speech as compared with some reference system, the comparison being made by adjusting the "line" in the reference system so that speech is reproduced by it with the same loudness as by the system under test. The number of units in the line is then taken as the "equivalent" of the system relative to the reference system.

Two such reference systems based on the two types of standard cable are in common use, and the specifications for their construction are quite well standardized. No such general agreement exists, however, on a reference system calibrated in βl units.

It should be noted that the use of these reference systems based on miles gives the results in miles of standard cable, and not in "800 cycle miles." They are, therefore, subject to the same objections as were raised to the mile of standard cable as a unit. The transmission of the system under test is expressed in terms which depend upon the particular distortion introduced by the standard cable. Furthermore,

owing to the difference in impedance between the cable and the terminal instruments reflection effects enter in such a way that when only a small amount of cable is in the circuit the loudness actually increases with increase of "line" up to a certain point beyond which it decreases. As a result certain values of reproduction can be obtained with two distinct line settings.

That the reference systems now standard are not suitable for expressing transmission equivalents in *TU* is obvious. The Bell System has therefore, undertaken the development of a transmission reference system designed primarily for use with the new unit. While this is not fully developed and calibrated, a general idea may be given of the factors entering into its design and the form which it is taking.

In line with the fact that the *TU* is independent of frequency, a distortionless reference system was chosen as the ideal. It might be argued that such a system would be unsuitable for comparison with practical systems because of their distortion. However, the systems in actual use vary in distortion over a wide range, from heavy loaded cable circuits on the one hand to the very high quality systems used for transmitting and reproducing music and other entertainment material on the other.[6] It would, therefore, be impossible to select a reference system having a distortion typical of operating conditions in general. Hence it seems preferable to refer all systems finally to a distortionless standard, thereby eliminating one variable factor.

The system which is being constructed to approximate this ideal has as its adjustable portion an artificial line of 600 ohms characteristic impedance made up of resistances and cali-

[6] High Quality Transmission and Reproduction of Speech and Music; W. H. Martin and H. Fletcher; Journal of the A. I. E. E., March, 1924, p. 230; Electrical Communication, Vol. II, No. 4, April, 1924.

brated in *TU*. At one end is a transmitting circuit and at the other a receiving circuit. These are made as nearly distortionless as possible. Their impedances are 600 ohms pure resistance, so that no reflection effects enter at the junctions with the line. The transmitter is of the condenser type, and is connected with a multi-stage amplifier. The receiving circuit contains an amplifier and a specially damped receiver.

These circuits are to be defined by assigning to them certain conversion ratios between the acoustic and electric portions of the system. In order to minimize the readjustment of working concepts based on the present reference system it is proposed to make the receiving circuit in the new system of approximately the same efficiency as that in the old. The transmitting efficiency is then to be so chosen that some particular reproduction efficiency which is representative of operating conditions will correspond to the same equivalent in *TU* with reference to the new system as it does in miles with reference to the old. Efficiencies in the neighborhood of this will then differ very little on the two systems.

The practical determination of the transmitting efficiency necessary to satisfy this condition will require a very extended series of observations, since the error in a single observation is likely to be large where the distortion is so different in the two systems. Owing to this difficulty of comparison it is probable that the distortionless reference system will be used in practice only for circuits of relatively high quality. Such routine talking comparisons as are made on ordinary commercial circuits will probably be made against sub-standards each having distortion typical of a limited class of commercial circuits. These substandards, will be calibrated against the transmission reference system by extended laboratory tests.

In the actual use of the *TU*, time saving devices such as tables, curves and approximate relations are important. Of these the ordinary slide rule has probably the widest application, as it permits the conversion between a power or current ratio and *TU* to be made by a single setting. For more accurate results a table of common logarithms is sufficient. The curves of

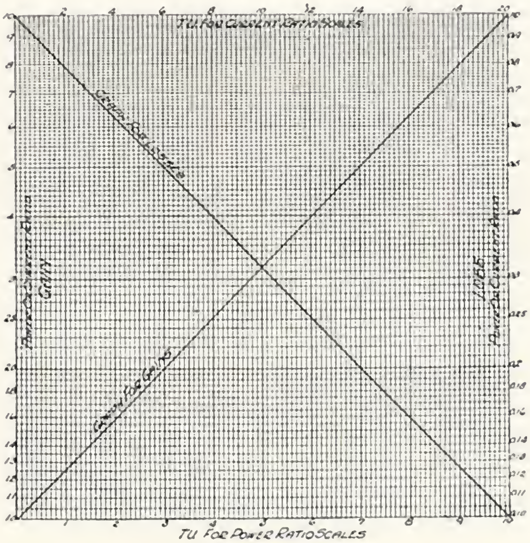

Figure 1—Transmission Unit Diagram. For power or current ratios greater than 10, move the decimal point to the left until the ratio lies between 1 and 10; and for each place the decimal point is moved, add 10 or 20 to the figures on the lower or upper scales, respectively. For power or current ratios less than 0.1, move the decimal point to the right until the ratio lies between 0.1 and 1; and for each place the decimal point is moved, add 10 or 20 to the figures on the lower or upper scales, respectively

Figure 1 furnish a simple means of graphical conversion. For very rough mental estimates the approximate relations of Table 1 are convenient. The error involved in the use of such approximations is indicated by the more exact figures given in parenthesis.

Tables 2 and 3 furnish the necessary constants for converting from the *TU* to other units.

TABLE 1

Number of *TU*	Approximate Power Ratio			
	Gains		Losses	
	Fractional	Decimal	Fractional	Decimal
1	5/4	1.25 (1.259)	4/5	.8
2	3/2	1.6 (1.585)	2/3	.63
3	2	2. (1.995)	1/2	.5
4	5/2	2.5 (2.512)	2/5	.4
5	3	3.2 (3.162)	1/3	.32
6	4	4. (3.981)	1/4	.25
7	5	5. (5.012)	1/5	.2
8	6	6. (6.310)	1/6	.16
9	8	8. (7.943)	1/8	.13
10	10	10. (10.)	1/10	.1
20	100	100. (100.)	1/100	.01
30	1000	1000. (1000.)	1/1000	.001

TABLE 2

	TU	800 cycle mile	βl unit
1 *TU* =	1.	1.056	.1151
1 800 cycle mile =	.9467	1.	.1090
1 βl unit =	8.686	9.174	1.

TABLE 3

Multiply	by	to Obtain
TU	1.056	800 cycle miles
TU	0.1151	βl units
800 cycle miles	0.9467	*TU*
800 cycle miles	0.1090	βl units
βl units	9.175	800 cycle miles
βl units	8.686	*TU*

In the United States of America

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Boston	Denver	Milwaukee	Philadelphia	Seattle
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Buffalo	Duluth	Nashville	Portland	Syracuse
Charlotte	Grand Rapids	Newark	Providence	Tacoma
Chicago	Houston	New Haven	Richmond	Youngstown
Cincinnati	Indianapolis	New Orleans	St. Louis	

In Other Countries

Africa, South—
Western Electric Company, Ltd., Johannesburg

Argentine—
Cia Western Electric Argentina, Buenos Aires

Australia—
Western Electric Company (Australia), Ltd., Sydney

Austria—
Vereinigte Telephon und Telegraphen Fabriks A. G., Vienna

Belgium—
Bell Telephone Manufacturing Company, Antwerp

Brazil—
International Western Electric Company, Inc., Rio de Janeiro (Rua dos Ourives 91-1)

Canada—
Northern Electric Company, Ltd., Montreal

China—
China Electric Company, Ltd., Peking and Shanghai

France—
Le Matériel Téléphonique, Paris

Great Britain—
Western Electric Company, Ltd., London, W.C.2

Holland—
Bell Telephone Manufacturing Company, The Hague

Hungary—
United Incandescent Lamps and Electrical Company, Ltd., Ujpest 4 near Budapest

Italy—
Western Electric Italiana, Milan

Japan—
Nippon Electric Company, Ltd., Tokyo

Norway—
Western Electric Norsk Aktieselskap, Christiania

Spain—
Telefonos Bell, S. A., Barcelona (Granvia Layetana 17)

Straits Settlements—
Western Electric Company, Ltd., Singapore

Switzerland—
Bell Telephone Manufacturing Company, Berne

OR THE

International Western Electric Company

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